are increased, thereby increasing the number of bits per symbol transmitted using the same symbol rate. Typically, increasing the number of amplitude levels of a CAP signal increases the likelihood of errors in the signal due to noise. However, proper adaptation of the pre-coder matrices compensates for these errors. Thus, in the case of the CAP symbol stream, the number of bits is increased from, for example, four bits to 8 bits, then 16 bits, then 32 bits, and so on until a maximum desired level is reached.

FIG. 6 comprises a graphical representation of a learning curve for a defined number of iterations according to the present invention. specifically, a graph 600 shows a MSE/Power (axis 602) vs. a number of iterations (axis 604) during the transmitter 104 and receiver's 108 training period. A curve (plot 606) represents the ratio of mean squared errors to the average power at the summer vs. the number of iterations in which the pre-coder algorithm 500 is executed. The inverse of the ratio is the approximation of the signal to noise ratio. At the beginning of the training period, the gain of the cross-talk transfer functions has been increased to create a condition with an approximate signal to noise ratio of 8 dB. After about 2000 iterations, the SNR increases to about 22 dB. At about 7500 iterations, the signal to noise ratio reaches about 23.5 dB.

The inventors have determined that a signal to noise ratio of 23.5 dB will allow a virtually error free operation while a signal to noise ratio of 8 dB gives greater than 10% symbol error rate.

FIG. 7 depicts a graphical representation of the learning curve of FIG. 6 for a longer period of iterations. Graph 700 shows the MSE/Power (axis 602) vs. the number of iterations (axis 604) during the transmitter 104 and receiver's 108 training period for 80,000 iterations. At the beginning of the training period, a curve (plot 702) begins with a signal to noise ratio of about 8 dB. However, unlike the curve (plot 606) that fell within a 5 dB spread from 1,000 to 8,000 iterations, the present curve (plot 702) averages a 2 dB spread from 10,000 to 80,000 iterations. Transmitter 104 and receiver 108 have ten times as much time to train. This results in greater accuracy for the training

period.

FIG. 8 depicts a constellation diagram of the communications system of FIG. 1 before pre-coding. Specifically, graph 800 comprises a *Y* axis 802 and a X axis 804. Extending perpendicularly from *X* axis 804 are five evenly spaced lines labeled X_1, X_2, X_3, X_4 and X_5. Similarly, five evenly spaced lines labeled Y_1, Y_2, Y_3, Y_4 *and* Y_5 extend perpendicularly from *Y* axis 802. The intersecting of lines X_1, X_2, X_3, X_4 *and* X_5 with lines Y_1, Y_2, Y_3, Y_4 and Y_5 creates 16 squares labeled *Q1* up to *Q16* respectively. The lines form a boundary circumscribing each square resulting in a decision boundary.

Disposed within the squares are points 806 representing data levels. The points are shown scattered in a random order throughout the 16 squares. Points falling within a square create a condition. However, points falling on the boundary of a square result in estimation errors because the receiver 108 will not know the correct square to assign the point to. Ideally, points 806 should be centered within each square. Graph 800 shows points disposed on the boundaries of square *Q1, Q4, Q5, Q8, Q9, Q12* and *Q16*.

FIG. 9 depicts a constellation diagram of the communications system of FIG. 1 after pre-coding according to the present invention. Graph 800 comprises *Y* axis 802 and *X* axis 804. Extending perpendicularly from *X* axis 804 are lines X_1, X_2, X_3, X_4 and X_5. Similarly, five lines labeled Y_1, Y_2, Y_3, Y_4 and Y_5 extend perpendicularly from Y axis 802. The intersecting of lines X_1, X_2, X_3, X_4 and X_5 with lines Y_1, Y_2, Y_3, Y_4 and Y_5 creates 16 squares labeled *Q1* up to Q16 respectively.

Graph 900 shows an equal number of points being grouped and centered within each of the sixteen squares. Estimation errors have been eliminated due to pre-coding the symbol stream.

FIG. 10 depicts a high level block diagram of an embodiment of a controller suitable for use within a transmitter. Specifically, FIG. 10 depicts a high level block diagram of a transmitter 104 suitable for use in the communication system 100 of FIG. 1. The voice transmitter controller 104C comprises a microprocessor 1020 as well as memory 1030 for storing

programs 1050 such as pre-coding method 500 which was described more fully above in a discussion of FIG. 5. The microprocessor 1020 cooperates with conventional support circuitry 1040 such as power supplies, clock circuits, cache memory and the like as well as circuits that assist in executing the software methods of the present invention.

The transmitter controller 104C also comprises input/output circuitry 1010 that forms an interface between the microprocessor 1020, the DSL network 102, second transmission medium 114, and other transmitter circuitry (not shown).

Although the transmitter controller 104C is depicted as a general purpose computer that is programmed to perform pre-coding, transmitting and receiving functions in accordance with the present invention, the invention can be implemented in hardware, in software, or a combination of hardware and software. As such, the processing steps described above with respect to the various figures are intended to be broadly interpreted as being equivalently performed by software, hardware, or a combination thereof. It will be appreciated by those skilled in the art that the transmitter controller 104C provides sufficient computer functionality to implement the invention as described above.

The above described invention provides adaptive pre-coding which is very suitable for multi-user transmission systems in which the transmitters are collocated and the receivers are separately located. This scenario fits the model of the typical downstream transmission in most systems such as VDSL system. That is, the transmission of data from the service provider to individual users. The pre-coding provides a very effective means of reducing or eliminating the effect of far-end-cross-talk in a multi-user environment.

Although various embodiments which incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.